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INFORMAL REPORT

CORRELATION SIGNAL PROCESSING FOR DEPTH SOUNDING

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NAVAL OCEANOGRAPHIC OFFICE
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INFORMAL REPORT

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ABSTRACT*

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GEORGE J. MOSS, JR.
Development Engineering Division
Instrumentation Department

GEORGE M. WALSH
Submarine Signal Division
Raytheon Company

This report has been reviewed and is approved for release as an UNCLASSIFIED Informal Report

A. H. HAYNES
Director,
Development Engineering Division

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CORRELATION SIGNAL PROCESSING FOR DEPTH SOUNDING

by

George J. Moss, Jr.
U.S. Naval Oceanographic Office
Washington, D.C.

George M. Walsh
Raytheon Company
Portsmouth, Rhode Island

ABSTRACT

Replica correlation acoustic depth sounders have several significant advantages over conventional systems. Although development has been primarily oriented toward bathymetric survey missions, replica correlation systems can provide significant improvements for both deep submersibles and support ships. Greatly improved resistance to depth measurement errors, resulting from impulsive noise sources commonly encountered with submersibles and support ships, is provided by hard clipping of the signal and integration over the pulse length. Better resolution and sub-bottom penetration can be obtained, due to the increased signal-to-noise ratio resulting from the signal processing gain. The requirement for manual gain or threshold adjustments during operations is eliminated by the normalized output noise characteristics of hard clipped correlators, and the reliability of digital depth data is improved. A computer simulation of the performance of a replica correlation echo sounder has verified theoretical results in the areas of signal duration and bandwidth limitations, improved signal waveform design, and the effects of quantization and sampling. Further at-sea testing of a complete system is planned, and hardware has been developed for this purpose.

INTRODUCTION

Submersible pilots have very little time to read and interpret analog echo sounder displays during critical diving operations such as ascent and descent. Yet these are precisely the times that a pilot has the greatest need for depth and altitude information. Reliable digital displays on the upward-looking and downward-looking echo sounders can reduce the pilot's workload during critical maneuvers, permitting him to concentrate on his primary task of operating the vehicle. However, conventional echo sounders with digital readouts are much more sensitive to noise than those with only analog or graphic readouts. Isolated noise impulses which would not be noticed on an analog fathogram can cause false digital depth readings.

Conventional short-pulse echo sounders also require frequent adjustments because of changes in the signal and noise levels. When conditions change, the gain control must be turned up to detect weak signals, or down to inhibit false depth readings. In a submersible, this distracts the pilot from his other operational tasks.

A new type of echo sounder which uses replica correlation signal processing can provide reliable digital depth data and also

hands-off operation.[1] Low error rates result from the signal processing gain and the improved resistance to impulsive noise sources. The requirement for manual gain or threshold adjustments during critical operations is eliminated because the output noise characteristics are continuously normalized.

PRINCIPLES OF OPERATION

Correlation echo sounders discriminate against noise by utilizing long pulses, which permit the transmission of high energy signals at normal power levels. Correlation signal processing utilizes this energy to enhance signals and suppress noise, while retaining the good time resolution of short-pulse echo sounders. Signal enhancement equivalent to a hundred-fold increase of peak power is practical and has been demonstrated.

Figure 1 compares the transmitted, received, and processed signals of short-pulse and correlation echo sounders. In the short-pulse system, the received signal is corrupted by noise. Processing typically consists of envelope detection, which produces an output pulse approximately equal in width to the received pulse, and does not improve the signal-to-noise ratio.

Correlation echo sounders transmit much longer signals with approximately the same spectral content. A correlation signal processor compares the received waveform with a replica of the transmitted waveform several thousand times each second, and produces an output pulse when the two waveforms match. It does this by multiplying the two waveforms together, and averaging the resulting cross-product over the length of the replica waveform. This averaging process reduces the relative noise level at the correlator output. The multiplication is performed by comparing the polarity of the replica and received signal plus noise after each has been hard clipped. The clipping operation provides the required signal normalization for hands-off operation.

The performance of a correlation echo sounder can be compared to a conventional short pulse system with equal depth resolution and peak power capability. A short-pulse echo sounder with a pulse length of 0.5 ms and a peak power of 100 watts would transmit 0.05 joule of energy during each pulse. A correlation echo sounder with the same peak power limit and a pulse length of 50 ms would transmit 5 joules per pulse, without sacrificing resolution. This 100-fold increase in transmitted energy represents a potential 20 db improvement in the signal-to-noise ratio, for continuous noise.

Figure 2 shows the output of a clipped correlator, as a function of the input signal-to-noise ratio. The output level is referenced to the steady noise generated by the correlator in the absence of a signal. Signal-to-noise improvements of 18 to 20 db are noted for signals weaker than the ambient noise level. This indicates efficient use of the additional energy provided by the long

pulse. For positive input signal-to-noise ratio, the correlator output saturates because the input signal is assumed to be hard clipped.

Figure 2 also shows a decrease in the instantaneous noise level, for high input signal-to-noise. This phenomenon shows up on a fathogram as a light streak in an otherwise dark background, immediately above the bottom, as illustrated in Figure 3.

The performance of echo sounders, particularly when digital readouts are used, depends greatly on the type of noise encountered as well as its magnitude. Signal and noise levels vary significantly with time; because of changes in bottom reflectivity, bottom slope, and depth; and because of the intermittent nature of hydrodynamic, biological, electrical, and other noise sources. In many cases the noise is decidedly non-gaussian, and is characterized by a limited number of very large impulses.

An example of non-gaussian impulsive noise is provided by Figure 4, which illustrates noise produced by the impact of gas bubbles against a flush-mounted 12 KHz hydrophone on the USNS SILAS BENT (AGS-26). These bubbles are formed by release of dissolved gases in local low-pressure areas created by the movement of the ship through the water. They are swept past the hydrophone in groups or clouds, where they produce attenuation as well as noise. The similarity between the noise and the actual echo, in the case of a short-pulse echo sounder, makes it virtually impossible to discriminate against the noise. Although the impulsive noise observed on board submersibles is caused by different physical mechanisms, it creates similar detection problems. Echo sounder performance will be degraded by this impulsive noise far more than predicted by the simple, continuous, white Gaussian noise models which are often used for system comparisons.

Correlation echo sounders are very good at discriminating against impulsive noise for two reasons. First, hard clipping reduces the amplitude of the noise pulses. Second, noise pulses shorter than the transmitted pulse duration make proportionately smaller contributions to the correlator output due to the averaging performed by the correlation process.

IMPLICATIONS TO THE OPERATOR

Reliability of Data

When one views an analog depth profile, the eye tends to reject occasional noise pulses which do not line up with adjacent depth soundings. Commercially available digital depth trackers, on the other hand, rely primarily on pulse amplitude for recognition of the reflected signal. In Figure 4 any threshold low enough to produce a high detection probability between bursts of noise would result in an incorrect depth reading during noise bursts.

Figure 5 illustrates how correlation signal processing can improve the reliability of a digital echo sounder operating in a particularly noisy environment. Figure 5 (a) shows the output waveform of a conventional short-pulse echo sounder. An ambient noise level 1/3 as large as the echo level is assumed, at the time of the first echo. However a four-fold increase in the background noise level, accompanied by several very large noise impulses, is assumed to occur at the time of the second echo. Such an increase in the noise level might result from operation of a propulsion motor or a thruster. An incorrect depth reading occurs because the noise exceeds the detection threshold. The threshold level cannot be increased high enough to prevent false depth readings, because it would then exceed the echo level, and depth measurement would be impossible.

Figure 5 (b) shows the unprocessed received waveform in a correlation echo sounder, under the same conditions. The only difference is a greater transmitted pulse width and correspondingly wider echoes. Figure 5 (c) shows the output of the correlation processor. Reliable echo sounding results from the fact that the threshold is greater than the noise, and the echo levels are greater than the threshold.

Hands-Off Operation

The pulsating nature of noise makes the adjustment of the signal-recognition threshold for a short-pulse digital echo sounder very critical. If the threshold level is too high, depth readings will not be taken; if it is too low, the readings will be incorrect. Furthermore the optimum threshold (or gain) adjustment is highly sensitive to changing signal and noise levels. Consequently inability to stabilize the noise level of short-pulse digital echo sounders results in a requirement for constant operator attention.

Replica correlators have very stable output noise levels. The maximum output noise level occurs when the input noise reaches the clipping level; sufficient gain is provided so that the system is always clipping. Even very large noise impulses do not increase the output noise level significantly. The high stability of the output noise level permits the operator to set the detection threshold level (or gain) once and forget about it. No further adjustment is required to prevent false depth readings, even if the input noise level increases.

SYSTEM HARDWARE

Figure 6 illustrates an experimental correlation processor. It was developed for at-sea experiments to determine the best operating parameters for a correlation echo sounding system, and accordingly features flexibility in regard to frequency, transmitted waveform, pulse width, and other parameters. Once the optimum operating parameters have been determined, it will be possible to design a much simpler unit

for operational use. The simplified unit will require no operational controls.

CONCLUSIONS

Correlation signal processing can improve the reliability of echo sounding data by increasing the tolerance for steady noise by 20 db, and by eliminating the false depth readings normally caused by very large noise impulses. If a burst of noise is so great as to exceed even the improved noise tolerance, the result will be a temporary hiatus in depth readings, rather than a false reading.

This increase in data reliability is sufficient to permit the use of digital displays on both up-looking and down-looking echo sounders on submersibles. The digital displays will be free of the erroneous depth readings that are normally caused by noise, and critical adjustments to the echo sounders will not be required during operations.

A flexible experimental correlation processor has been developed for at-sea determination of the optimum parameters for a correlation echo sounding system.

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REFERENCES

1. Walsh, G.M., "Final Report: Correlation Echo Sounder Program: Phase I," Raytheon Company, Submarine Signal Division, Portsmouth, Rhode Island, May 1, 1969 (Prepared under Contract N62306-68-C-0202, for U.S. Naval Oceanographic Office).

BIBLIOGRAPHY

1. Allen, W.B., and E.C. Westerfield, "Digital Compressed Time Correlators and Matched Filters for Active Sonars," JASA, Vol. 36, No. 1, January 1964, pp. 121-139.

2. Chramiec, M.A., "Improvements to Sub-bottom Profiling Sonars Through Application of Correlation Signal Processing," M.S. Thesis, Ocean Engineering Department, University of Rhode Island, 1969.

3. Chramiec, M. A. and G. M. Walsh, "Sub-bottom Profiling With a Replica Correlation Receiver," UST, September 1966.

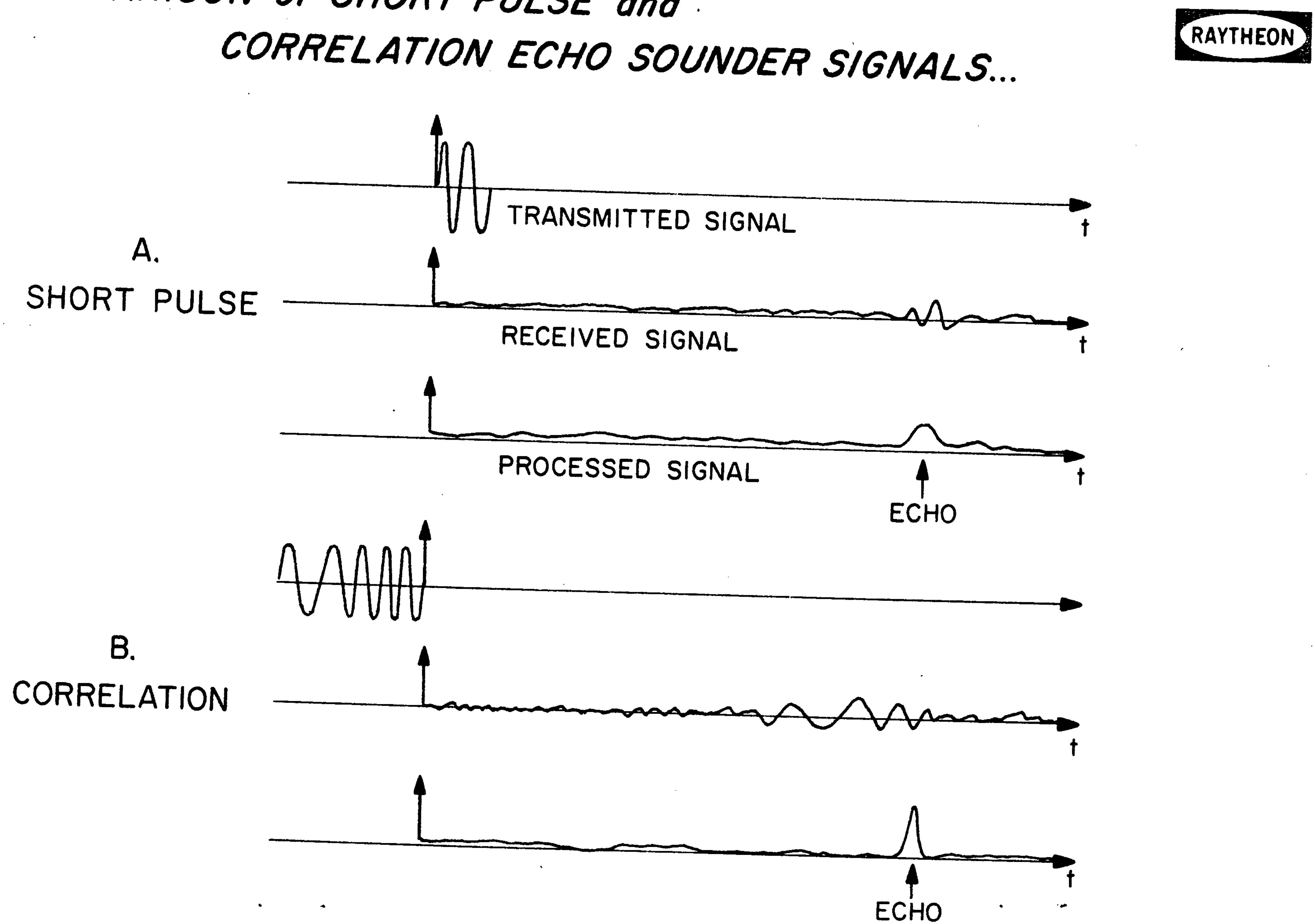
4. Clay, C.S., W.L. Liang, and S. Wisotsky, "Seismic Profiling With a Hydroacoustic Transducer and Correlation Receiver," JGR, Vol. 69, 1964, pp. 3419-3428.

5. Krause, D.C., M.A. Chramiec, G.M. Walsh, S. Wisotsky, "Seismic Profile Showing Cenozoic Development of the New England Continental Margin," JGR, Vol. 71, No. 18, September 15, 1966.

6. Nawar, F.G., W. L. Liang, and C.S. Clay, "A Pulse Compression Echo Sounder for Ocean Bottom Surveys," JGR, Vol. 71, No. 22, November 15, 1966, pp. 5279-5283.

FIGURE 1

COMPARISON of SHORT PULSE and CORRELATION ECHO SOUNDER SIGNALS...



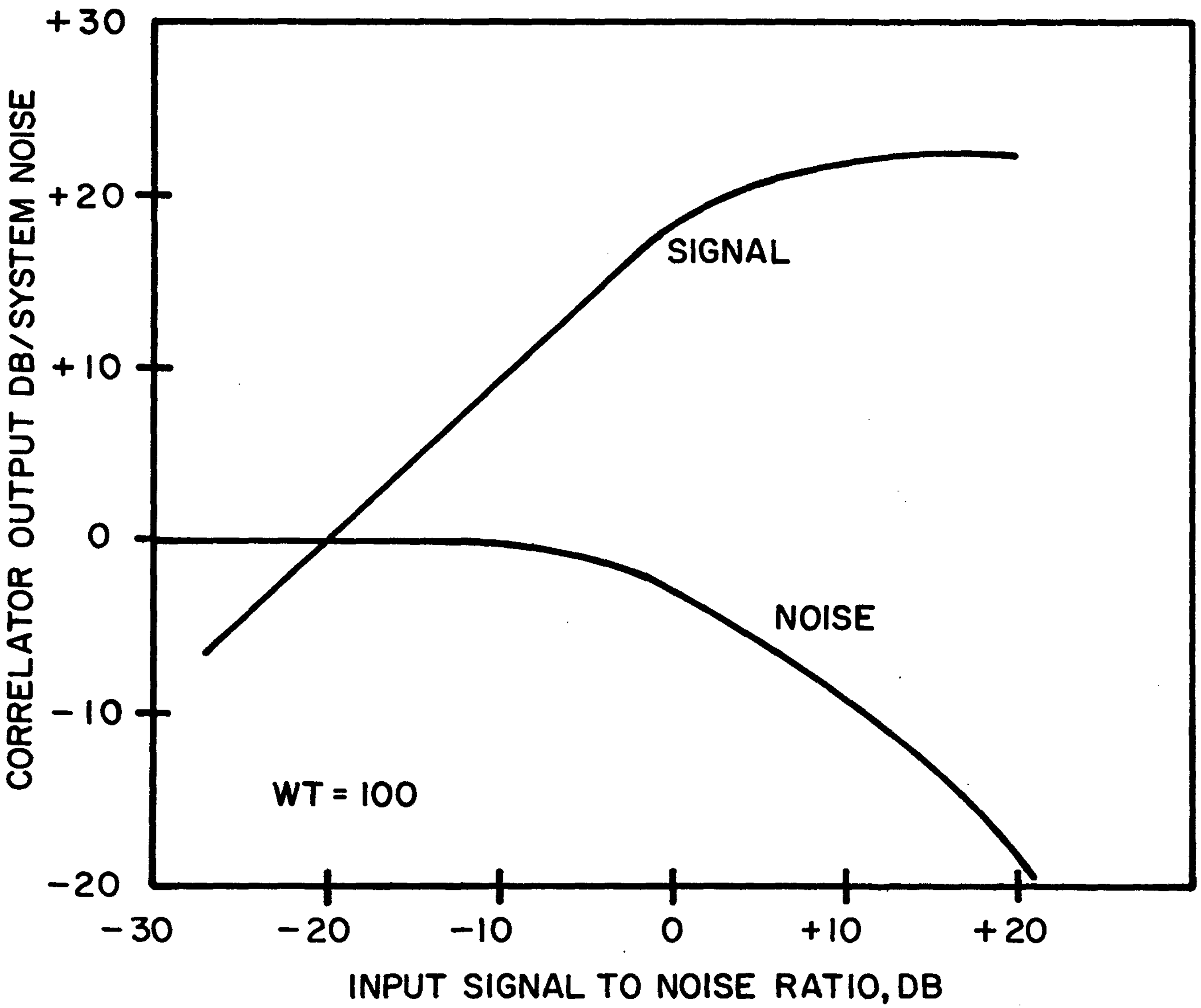


FIGURE 2

Clipped Replica Correlation Output Signal
and Noise Characteristics

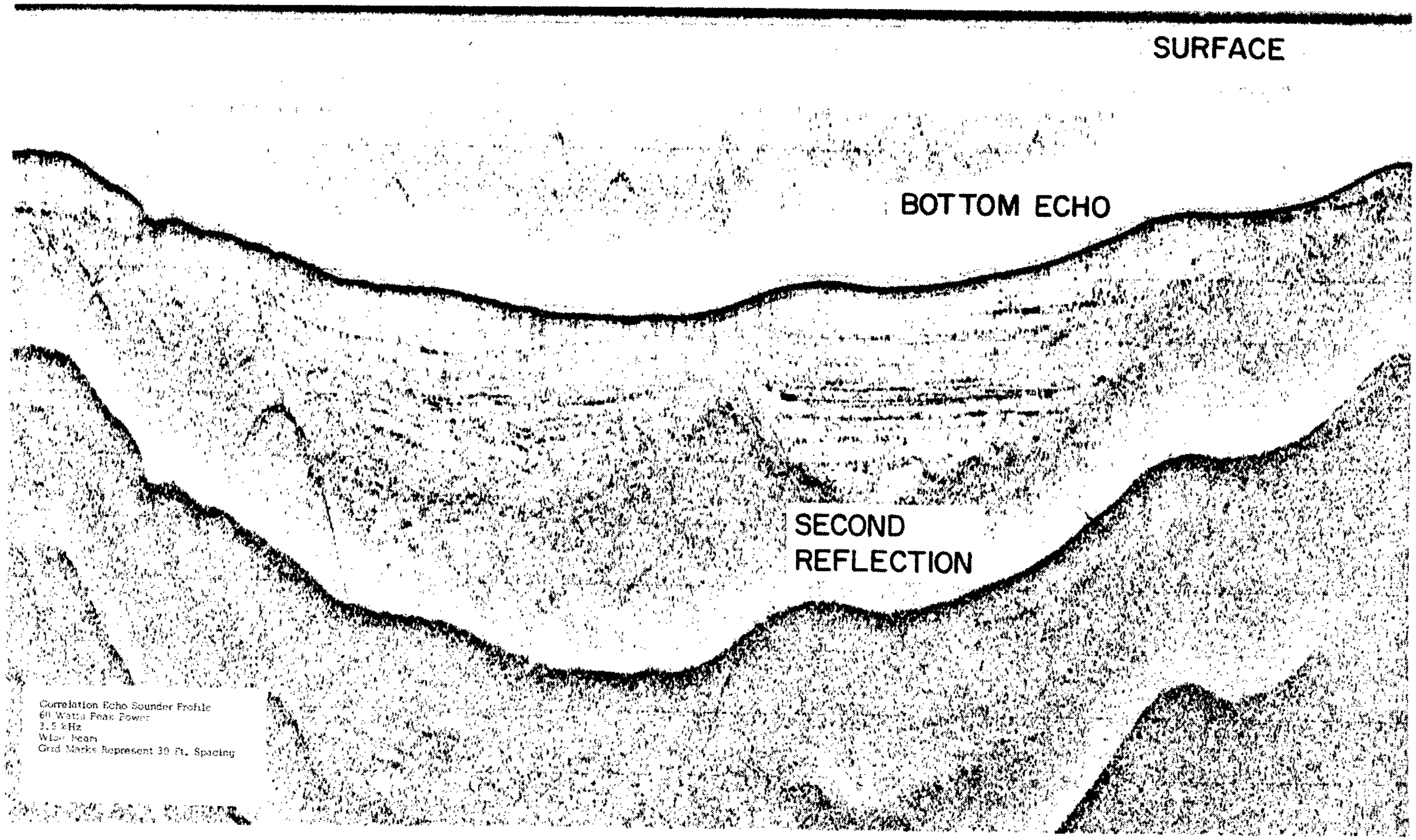


FIGURE 3

Correlation Echo Sounder Sub-Bottom Profile

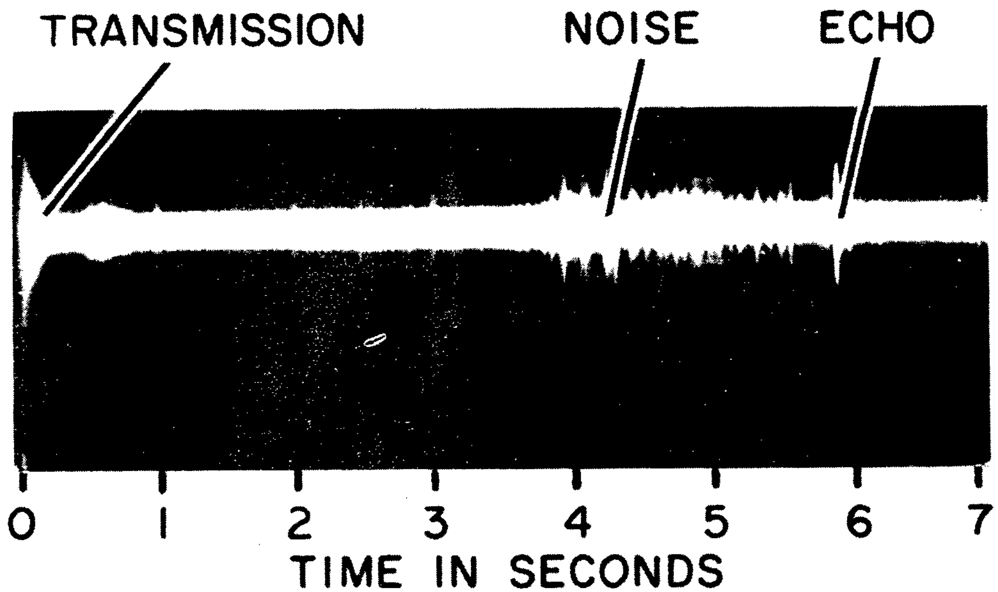
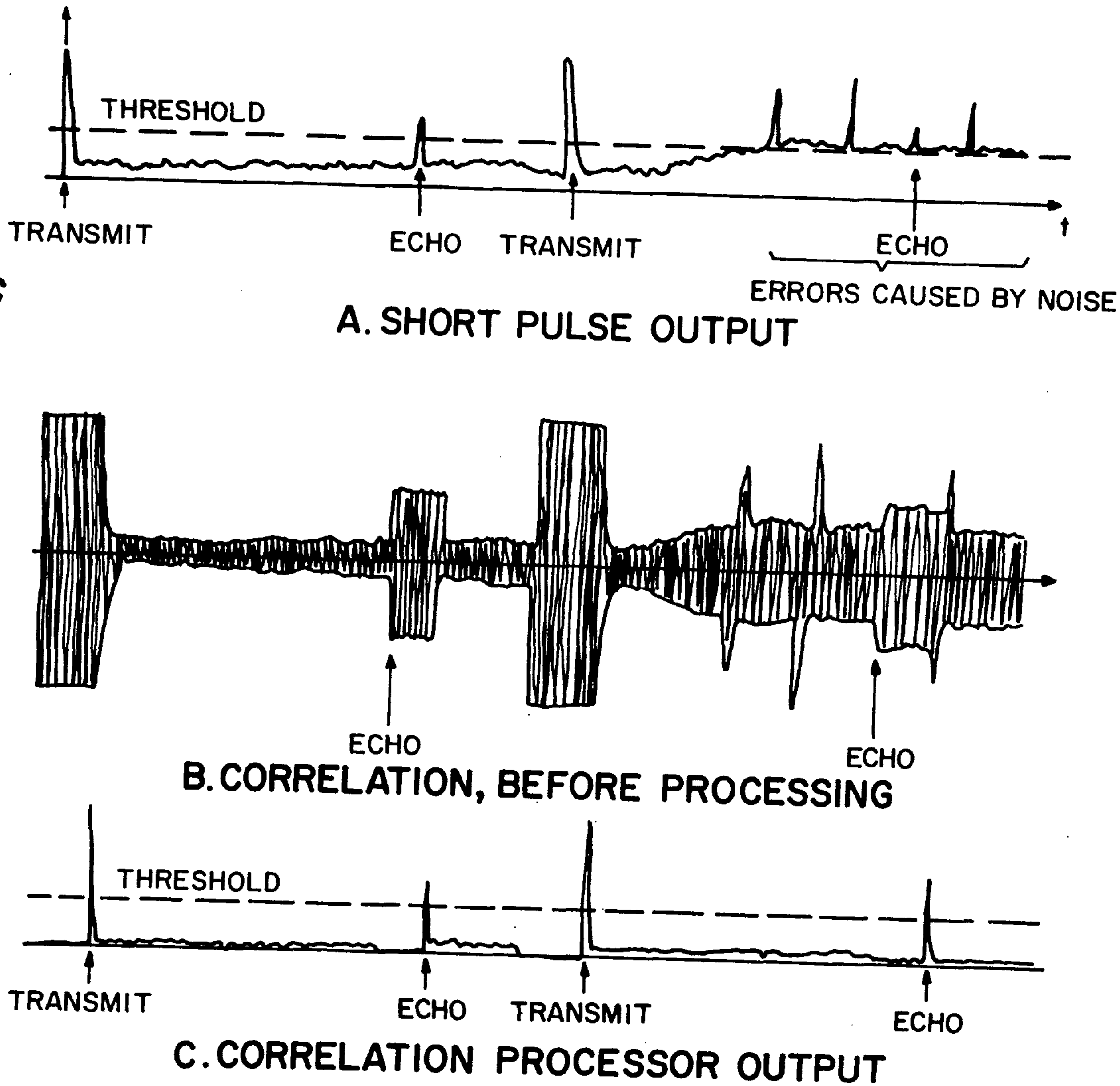


FIGURE 4

Noise Pulses Due to Bubbles
(USNS Silas Bent 12 KHz Echo Sounder)

FIGURE 5

REDUCTION OF ERROR RATE DUE TO CHANGING OR IMPULSIVE NOISE



A. SHORT PULSE OUTPUT

B. CORRELATION, BEFORE PROCESSING

C. CORRELATION PROCESSOR OUTPUT

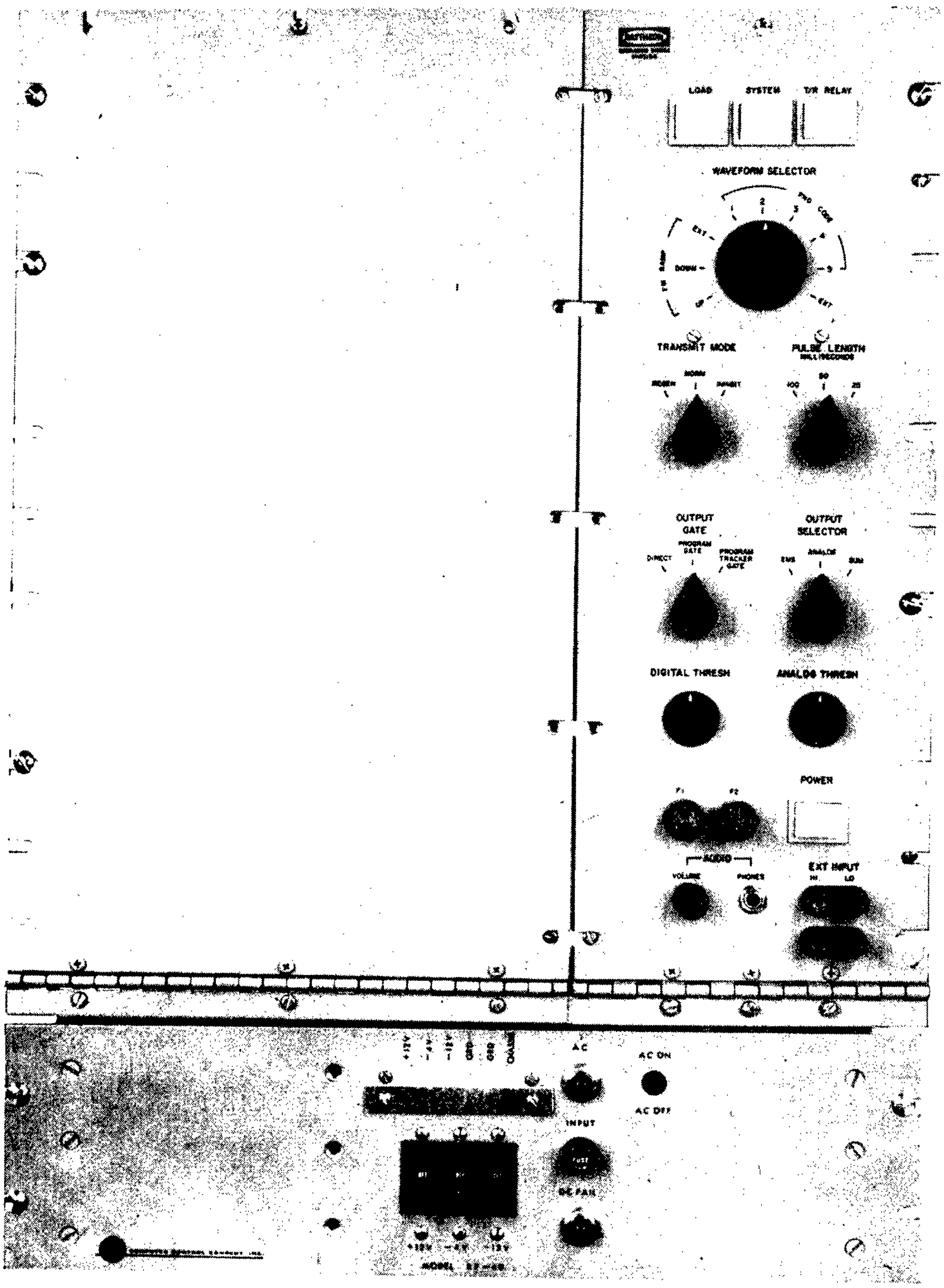


FIGURE 6

Experimental Correlation Echo Sounder

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Bathymetry						
Correlation						
Submersible						